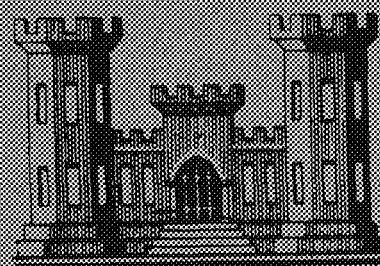


HURRICANE PROTECTION PROJECT

MYSTIC HURRICANE BARRIER

MYSTIC, CONNECTICUT

DESIGN MEMORANDUM NO. 1 HYDROLOGY AND HYDRAULICS



**DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.**

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HURRICANE PROTECTION PROJECT

MYSTIC, CONNECTICUT

DESIGN MEMORANDA INDEX

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1	Hydrology and Hydraulics	30 Sept 1966	
2	General Design and Site Geology		
3	Concrete Materials		
4	Real Estate		
5	Embankments and Foundations		
6	Navigation Gate and Floodwalls		

HURRICANE PROTECTION PROJECT
MYSTIC, CONNECTICUT

DESIGN MEMORANDUM NO. 1

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HURRICANE PROTECTION PROJECT
MYSTIC, CONNECTICUT

DESIGN MEMORANDUM NO. 1

HYDROLOGY AND HYDRAULICS

1. PURPOSE

The purpose of this memorandum is to describe the hydrologic and hydraulic criteria applicable to the design of the hurricane protection project in Mystic, Connecticut at the mouth of the Mystic River. Part I - Hydrology includes sections on watershed description, climatology, design riverflows and interior ponding. Part II - Tidal Hydraulics includes sections on normal tide conditions, experienced tidal flood levels, frequency of tidal flooding, determination of design tidal flood levels, associated wave heights, wave runup and overtopping and modified tidal flooding.

2. DESCRIPTION OF PROJECT

The plan of protection will consist of a 3,200-foot main barrier across Mystic Harbor at the northern end of Sixpenny Island, extending from high ground on the west shore to Mason Island on the east; an earth barrier at the causeway to Mason Island terminating with a concrete wall at the west end; and a series of earth dikes across lowland on Mason Island and in the area east of Mystic. The project, to be operated during hurricanes and severe coastal storms, will include the following structures:

a. A gated navigation opening in the main barrier, 75 feet wide with invert at -17.2 feet msl and centered on the existing navigation channel.

b. A high-level ungated 39-foot wide railway opening near Sixpenny Island. The authorized plan included a stoplog structure 6.5 feet high by 50 feet wide. As the result of a review of the operational problems and with the concurrence of the railroad, it is proposed to eliminate the stoplogs and allow restricted flow to enter the harbor storage during a hurricane.

c. A gated small boat opening 12 feet wide with invert at -6.0 feet msl in the causeway barrier.

d. A 30-foot wide stoplog opening at westerly end of causeway barrier.

A general plan of the project is shown on plate 1-1.

PART I - HYDROLOGY

3. DESCRIPTION OF MYSTIC RIVER WATERSHED

The Mystic River originates in the town of North Stonington in southeastern Connecticut. The watershed, shown on plate 1-2, is about 7.0 miles in length, 3.5 miles in width and has a total drainage area of 30.1 square miles upstream of the barrier. Included in this area are 700 acres of tidal area in Mystic harbor and 2.2 square miles of drainage area in Pequotsepos Brook which flows into the harbor on the northeast side. The elevation of the watershed varies from 400 feet msl in North Stonington to mean sea level in Mystic harbor. The Mystic River is a tidal estuary from the mouth to the community of Old Mystic, approximately 4 miles north of the barrier. North of Old Mystic the river falls 180 feet in approximately 3.5 miles from its origin at Long Pond. The topography is gently rolling, with the exception of Long Hill in the northern end. The river flows through numerous low swamplands which tend to retard flood runoff.

4. CLIMATE

The southern coastal area of New England has a temperate and changeable climate marked by four distinct seasons. Owing to the moderating influences of Long Island Sound and the Atlantic Ocean, and particularly the variable movements of high and low pressure systems approaching from the west or southwest, extremes of either hot or cold weather are rarely of long duration. In the winter, coastal storms frequently bring rainfall to the shore areas rather than snow as in the more northerly sections of Connecticut. In the summer, cooling relief from hot humid weather is provided by sea breezes from the south, thunderstorms from the west and cool air from the north. The prevailing winds are northwesterly in the winter and southwesterly in the summer. High winds, heavy rainfall

and abnormally high tides occur with unpredictable frequency. Hurricanes occur most frequently during the months of August, September and October.

5. TEMPERATURE

The mean annual temperature in the Mystic area, based on 84 years of record at New London prior to 1955, is approximately 50° Fahrenheit. January and February are the coldest months with an average temperature of about 30° F. and July the warmest with a mean temperature of 72° Fahrenheit. Freezing temperatures are common from late November through March. The lowest temperature recorded in the New London area was -17° F. on 9 February 1934 and the highest 100° F. on 26 August 1948. Table 1-1 is a summary of the mean monthly and maximum and minimum temperatures recorded at the U. S. Weather Bureau station at New London, Connecticut. The monthly mean temperatures are based on the period of record from 1871 to 1954, while the maximum and minimum temperatures are based on the period 1885 to 1954. The station in New London was discontinued in 1955.

TABLE 1-1

MONTHLY TEMPERATURES AT
NEW LONDON, CONNECTICUT
(Degrees Fahrenheit)

<u>Month</u>	<u>Mean</u>	<u>Maximum</u>	<u>Minimum</u>
January	29.8	67	- 7
February	29.8	68	-17
March	37.4	84	3
April	46.9	91	13
May	57.4	93	31
June	66.2	97	38
July	71.7	99	44
August	70.3	100	44
September	64.4	95	35
October	54.3	87	24
November	43.4	77	9
December	33.0	67	-12
ANNUAL	50.4	100	-17

6. PRECIPITATION

The average annual precipitation over the Mystic River basin is about 45 inches, and is rather evenly distributed throughout the year. Table 1-2 is a summary of the average monthly precipitation amounts at New London as measured over a period of 84 years prior to 1955.

TABLE 1-2

MONTHLY PRECIPITATION AT
NEW LONDON, CONNECTICUT
(Depth in Inches)

<u>Month</u>	<u>Mean</u>	<u>Maximum</u>	<u>Minimum</u>
January	4.04	8.61	.50
February	3.62	11.98	.43
March	4.20	10.96	.35
April	3.76	10.85	.64
May	3.49	9.03	.54
June	3.09	7.71	.01 (1949)
July	3.53	7.13	.44
August	4.39	16.44 (1874)	.48
September	3.41	11.21	.33
October	3.52	8.47	.20
November	3.83	9.40	.32
December	3.77	10.67	.73
ANNUAL	44.61	60.62 (1919)	30.05 (1896)

7. SNOWFALL

Snowfall at Mystic averages about 31 inches over the winter season. The snow cover usually reaches a maximum depth of about 15 inches in February. Monthly and annual average snowfall for New London, based on 49 years of record prior to 1946, are shown in table 1-3.

TABLE 1-3

MEAN MONTHLY SNOWFALL AT
NEW LONDON, CONNECTICUT
 (Average Depth in Inches)

<u>Month</u>	<u>Snowfall</u>	<u>Month</u>	<u>Snowfall</u>
January	8.6	July	0.0
February	9.8	August	0.0
March	4.3	September	0.0
April	0.8	October	Trace
May	0.0	November	1.6
June	0.0	December	5.8

Annual 30.8

8. STORMS

The Mystic River basin experiences three general types of storms: continental, coastal and those associated with thunderstorms. The rapidly moving continental or cyclonic storms that cross the basin from the west or southwest produce frequent periods of rainfall but are not extremely severe. Continental storms are apt to be more critical when they are of the stationary frontal type which may produce appreciable rainfall over a given area on several successive days. Thunderstorms may be of the frontal type associated with continental storms or of the local type which frequently produces high rainfall intensities over small areas. The most severe storms in the area have been of the hurricane type of tropical origin that move up the eastern seaboard. They are most likely to occur during the late summer and autumn months. The storms of September 1938, September 1944, August and September 1954 and August 1955 were of this type.

RAINFALL AND RUNOFF

9. HURRICANE RAINFALL

Among the greatest recent rainfalls associated with hurricanes in New England are those recorded for "Connie" and "Diane" in August 1955. Hurricane "Connie", 11-15 August, produced rainfall varying from about 4 to 6 inches over southern New England and ended a period of drought. A week later, 17-20 August, hurricane "Diane" brought rainfall of 16 to 20 inches to Connecticut and Massachusetts. These two hurricanes produced total rainfalls of 5.6 and 2.3 inches, respectively, at Groton, Connecticut. At West Mansfield, Massachusetts, about 60 miles northeast of Mystic, hurricane "Diane" produced a record rainfall of 13.1 inches in 55 hours, with 4.1 inches falling in 6 hours.

Excessive rainfall also was associated with the September 1938 hurricane. The maximum precipitation for this storm was concentrated over Portland, Connecticut, about 40 miles northwest of Mystic, where a total of 17 inches was recorded for the period 17-21 September. At New Haven, Connecticut, about 50 miles west of Mystic, the total rainfall was 11.6 inches.

Recorded rainfalls at 5 U. S. Weather Bureau stations near Mystic during a number of recent hurricanes are shown in table 1-4.

10. RUNOFF AND STREAMFLOW

There are no streamflow records for the Mystic River basin. However, there are several U. S. Geological Survey stream gaging stations located on other rivers in southern New England that are considered representative of the runoff characteristics of the Mystic River. Table 1-5 shows streamflow data for seven selected rivers along the southern New England coast.

11. UNIT HYDROGRAPH ANALYSIS

Unit hydrographs were developed for 3 gaged coastal streams with runoff characteristics similar to the Mystic River, namely, Wading River at West Mansfield, Massachusetts, Adamsville Brook at Adamsville, Rhode Island and Woonasquatucket River at Centerdale, Rhode Island. The Woonasquatucket River has a total drainage area at the Centerdale gage of 38.3 square miles. A unit hydrograph

TABLE 1-4

HURRICANE AND OTHER STORM RAINFALLS
VICINITY OF MYSTIC, CONNECTICUT
 (Accumulated Rainfall in Inches)

Hurricane or Other Storm	<u>Westbrook, Conn.</u>		<u>New London, Conn.</u>		<u>Groton, Conn.</u>		<u>Kingston, R. I.</u>		<u>New Haven, Conn.</u>	
	<u>Maximum*</u>		<u>Maximum*</u>		<u>Maximum*</u>		<u>Maximum</u>		<u>Maximum</u>	
	<u>24-Hour</u>	<u>Total</u>	<u>24-Hour</u>	<u>Total</u>	<u>24-Hour</u>	<u>Total</u>	<u>24-Hour</u>	<u>Total</u>	<u>24-Hour</u>	<u>Total</u>
Sept 1938	-	-	-	-	-	-	1.3	2.8	6.4	11.6
Sept 1944	2.8	6.2	3.4	7.1	-	-	2.4	4.4	4.0	8.5
Aug 1954 (Carol)	4.4	4.4	4.5	5.0	3.4	3.5	2.9*	2.9	2.75	2.75
Sept 1954 (Edna)	5.6	5.6	4.0	5.3	6.2	6.2	5.5*	5.5	5.55	5.55
Aug 1955 (Connie)	4.3	7.3	2.0	4.0	5.1	5.6	5.3*	5.7	3.2	3.6
Aug 1955 (Diane)	1.4	2.2	1.8	1.8	1.2	2.3	2.2*	3.2	3.2	4.3
Oct 1955	-	5.1	-	-	2.3	4.3	3.1*	4.65	3.8	5.9
Sept 1960 (Donna)	3.8	4.3	-	-	3.2	3.8	1.6	1.7	5.3	5.5
Sept 1961 (Esther)	2.9	3.0	-	-	7.4	7.6	6.5	7.1	2.0	2.0

* Nonrecording gage - values based on daily readings

TABLE 1-5

STREAMFLOW DATA
USGS GAGING STATIONS NEAR MYSTIC, CONNECTICUT

<u>Rivers & Locations of Gaging Stations</u>	<u>Drainage Area</u>	<u>Period of Record</u>	<u>Peak Discharge</u>		<u>Approximate Storm Rainfall (inches)</u>	<u>Date</u>
			<u>CFS</u>	<u>CSM</u>		
<u>Wedding River</u> W. Mansfield, Mass.	19.2	12	519	27	12	20 Aug 1955
<u>Adamsville Brook</u> Adamsville, R. I.	8.6	25	269	31	4-5	12 Sept 1954
<u>Woonasquatucket River</u> Centerdale, R. I.	38.3	24	1,100	29	4-5	12 Sept 1954
<u>Yantic River</u> Yantic, Conn.	88.6	36	13,500	153	10	21 Sept 1938
<u>E. Branch Eightmile R.</u> North Lyme, Conn.	22.0	38	2,950	134	10	21 Sept 1938
<u>W. Branch Eightmile R.</u> North Plain, Conn.	18.6	28	2,350	126	8	15 Oct 1955
<u>Mamunketesuck River</u> Clinton, Conn.	11.6	24	1,500	129	4-5	11 Sept 1954

was also developed for the 13.8 square mile area below Woonasquatucket Reservoir.

Comparative unit hydrograph characteristics for the Mystic River and the other three basins are shown in table 1-6. Snyder coefficients were selected for the Mystic River based on values derived for the above three basins, and a synthetic 3-hour unit hydrograph was developed. The adopted unit hydrograph for the Mystic River is shown on plate 1-3.

12. DESIGN RIVERFLOWS

Records from New England coastal streams do not show any major floodflows coincident with damaging hurricane tides. However, it is considered possible that rainfall preceding a hurricane could produce a relatively high riverflow at the time of barrier gate closure. The depth of ponding that would occur in the Mystic harbor area behind the barrier was determined for 4 combinations of tide, concurrent riverflow and proposed gate operation. Flood hydrographs were developed for the Mystic River from the following storms: the 10-year, 100-year, September 1938 and standard project. The September 1938 storm was developed from a transposition of the maximum rainfalls recorded in New England during this hurricane. The standard project storm, 100-year and 10-year, 24-hour rainfalls were determined from EM 1110-2-1411 and U. S. Weather Bureau Technical Paper No. 40, respectively.

Runoff hydrographs were developed by applying the respective rainfall excess values to the adopted unit hydrograph. The flood hydrographs and mass rainfall curves are shown on plate 1-3.

13. PONDING IN MYSTIC HARBOR

a. General. The water surface area of the harbor upstream of the barrier will be 700 acres at mean sea level. This area will provide a substantial volume of storage for interior runoff from the watershed. Between elevation 0.0 and 4.0 feet msl, the beginning of significant damage, the harbor will have a storage capacity of 3,400 acre-feet, equivalent to 2.1 inches of runoff from the drainage area of 30.1 square miles. Between elevations 2 and 4 feet msl, there will be 1,800 acre-feet of available storage, equivalent to 1.1 inches of runoff. Tentatively, it is proposed to close the gates on the navigation channels antecedent to arrival of the tidal surge when the rising ocean tide reaches elevation plus 2.0 feet msl. Area

TABLE 1-6

UNIT HYDROGRAPH DATA
MYSTIC HURRICANE PROTECTION PROJECT

	<u>Adamsville Brook</u> <u>Adamsville, R. I.</u>	<u>Woonasquatucket R.</u> <u>Centerdale, R. I.</u>	<u>Wading River</u> <u>West Mansfield, Mass.</u>	<u>Mystic River</u> <u>Mystic, Conn.</u>
Drainage Area (square miles)	8.6	13.8 (Reservoir-Centerdale)	19.2	30.1
L	6.0	6.4	9.1	12.5
L _{ca}	2.5	3.2	5.3	6.3
River Slope	0.00512	0.00295	0.000866	0.0056
T _{PR}	12	10	26	18
T _R	6	3	6	3
Q _{PR}	21.0	46.0	6.8	16.7
Q _{PR}	181	635	130	503
C _{TR}	5.3	4.0	8.1	4.8
C _p ⁶⁴⁰	250	460	177	300

capacity curves for Mystic harbor behind the barrier are shown on plate 1-4. Rating curves for the main barrier and small boat openings are shown on plate 1-5.

b. Design conditions. The adequacy of the design was tested for various combinations of riverflow and tide levels. The maximum elevation in the harbor area was determined for each of the following conditions:

(1) One-hundred year storm runoff with standard project tide. The barrier gates were assumed to be closed when the tide reached elevation 2.0 feet msl and would remain closed for 4 hours and 20 minutes. During this period the harbor would rise to a maximum elevation of 3.4 feet msl. At this elevation 850 acre-feet of runoff from the 100-year storm, 150 acre-feet of overtopping by the design tide and 200 acre-feet of flow through the ungated railroad opening would be in storage. A graphical illustration of this flood is shown on plate 1-3.

(2) Standard project flood with normal spring tide (navigation gates open). The barrier openings will pass the standard project flood discharge of 4,720 cfs with a head differential of about 0.2 foot. Therefore, with the water level on the oceanside of the barrier at elevation 1.4 feet msl (mean spring high water), the navigation openings will have adequate capacity to discharge the standard project flood in the Mystic River without producing an appreciable rise in the bay elevation.

(3) Transposed 1938 storm with 1938 hurricane tide. The barrier gates would be closed when the tide reached elevation 2.0 feet msl, and would remain closed for a period of 3 hours and 45 minutes. During this period the bay would rise to an elevation of 3.2 feet msl. At the maximum stage 994 acre-feet of runoff from the river and 46 acre-feet of flow through the ungated high level railroad opening would be in storage within the harbor area. A graphical description of the flood is shown on plate 1-3.

(4) Ten-year storm runoff with main barrier gate closed and inoperable. The 10-year flood hydrograph was routed through the bay area, assuming the main gate closed and all outflow limited to the small boat passageway. The peak inflow rate of 1,400 cfs would be reduced by the bay storage to a maximum outflow of 800 cfs. The harbor level would rise from an assumed initial elevation of 1.4 feet msl (mean spring high water) to 3.1 feet msl. A constant

oceanside elevation of 1.4 feet msl was assumed throughout the flood period. A lower oceanside elevation would have little effect on the resulting maximum bay elevation, since the small boat opening would act as a broadcrested weir with critical flow control once a head differential of approximately 2.0 feet is developed between the bay and the ocean.

14. INTERIOR DRAINAGE

Dikes "A" and "B" will intersect existing surface runoff and, therefore, some modification of the interior drainage systems will be required.

A small gated culvert will be installed under dike "A". The ground surface at dike "B" is relatively low and much of the land is presently idle. It is covered with a dense growth of brush and marsh vegetation. The existing surface drainage and ditches will be regraded and realigned as shown on plate 1-1. The proposed drainage system will insure rapid removal of tidal overflow as well as the normal interior runoff.

Additional structural details of the proposed drainage systems will be included in the appropriate feature design memorandums.

PART II - TIDAL HYDRAULICS

NORMAL CONDITIONS

15. NORMAL TIDES

Two high and two low tides occur each lunar day at Mystic harbor. The time interval for a complete tidal cycle averages about 12 hours and 25 minutes. Tidal data for Mystic harbor are summarized in table 1-7.

16. RECORDING TIDE GAGES IN THE EASTERN END OF LONG ISLAND SOUND

Records from four recording tide gages located in the eastern end of Long Island Sound were used in the design studies for the Mystic hurricane protection project. Locations of these gages are shown on plate 1-6, while table 1-8 provides general inventory data. All of

these gages are presently in operation with the exception of the Old Saybrook gage which was removed on 7 September 1965.

TABLE 1-7
NORMAL TIDES IN
MYSTIC HARBOR, CONNECTICUT

	<u>Feet</u>
Mean Tide Range	2.3
Mean High Water (above msl)	1.13
Mean Low Water (below msl)	1.17
Average Spring Tide Range	2.7
Mean Spring High Water (above msl)	1.4
Maximum Spring High Water (above msl)	2.4
Maximum Spring Tide Range	4.2
Estimated Minimum Low Water (below msl)	3.7

17. FACTORS INFLUENCING TIDES

The tides are subject to meteorological influences such as changes in atmospheric pressure and strong winds besides the normal gravitational effects of the sun and moon. A drop in barometric pressure of 1 inch of mercury will cause about a 1 foot rise in water levels. During coastal storms, tide levels often build up several feet above predicted elevations.

TABLE 1-8

TIDE GAGE INVENTORY DATA
EASTERN END OF LONG ISLAND SOUND

<u>No.</u>	<u>Location</u>	<u>Type of Gage</u>	<u>Period of Record</u>	<u>Agency</u>
1	Old Saybrook, Connecticut (Saybrook Marine Service, Inc. Dock)	A,B,C	20 Sept 1956 - 7 Sept 1965	NED
2	New London, Connecticut (State Pier)	A,B	4 June 1917 - 3 Nov 1917 11 June 1938 - To Date	USC&GS
3	Stonington, Connecticut (Dodson Boat Yard, Inc. Dock)	A,B,C	1 Oct 1956 - To Date	NED
4	Montauk, New York (Fort Pond Bay)	A,B	6 Sept 1947 - To Date	USC&GS

Type of Gage: (A) Recorder
 (B) Staff
 (C) Maximum Level

EXPERIENCED HURRICANE AND
SEVERE STORM TIDAL FLOODING

18. RECENT HURRICANES AND SEVERE STORMS

In the last 28 years Mystic has been subjected to tidal flooding from three major hurricanes and one severe storm, namely, hurricanes of September 1938 and 1944, August 1954 and the storm of November 1950.

The center of the 21 September 1938 hurricane entered Connecticut about 15 miles east of New Haven or about 35 miles west of Mystic and proceeded northerly at a rate of 50 to 60 mph. The center of hurricane "Carol", 31 August 1954, crossed the south shore of Connecticut in the vicinity of New London, about 6 miles west of Mystic, and followed a generally northerly path across New England. In the hurricane of 14 September 1944, the center of the storm passed inland between Charlestown and Point Judith, Rhode Island, about 20 miles east of Mystic, and continued in a northeasterly direction veering out to sea at Boston, Massachusetts. Flood levels along the Connecticut coast, based on observed high watermarks from the hurricanes of September 1938 and August 1954, are shown on plate 1-7. The tracks of selected major hurricanes are shown on plate 1-8. Detailed descriptions of the three major hurricanes of recent years are given in the Hurricane Survey Interim Report, Mystic, Connecticut, dated 15 July 1960.

Minor to moderate tidal flooding occurred at Mystic during hurricane "Donna", 12 September 1960, and during the storms of 7 November 1953 and 25 November 1950. The storm of November 1950 started as a disturbance from Virginia, intensified rapidly, and moved north-northeastward reaching New England on the 25th, and it resulted in the most violent storm of its kind on record. Tidal flooding occurred along the entire Connecticut coast and was particularly severe west of New Haven. The peak of moderate tidal flooding at Mystic harbor occurred at approximately the time of the predicted normal high tide. The recorded maximum gust and sustained 5-minute wind velocity at New Haven were 77 and 50 mph, respectively. Minor tidal flooding has also occurred from a number of other hurricanes and severe storms in the past 28 years. Recorded and predicted tidal heights at Mystic harbor for the hurricanes of 1938, 1944 and 1954 and the severe storm of November 1950 are shown in table 1-9.

TABLE 1-9

TIDAL FLOOD DATA FROM RECENT HURRICANES AND
OTHER STORMS, MYSTIC HARBOR, CONNECTICUT

<u>Hurricanes</u>	<u>Tidal Flood Crest</u>		<u>Predicted Tide Elevation* (ft,msl)</u>	<u>Max. Surge Above Pre- dicted Tide (feet)</u>
	<u>Time (EST)</u>	<u>Elevation (ft,msl)</u>		
21 Sept 1938	4:30 P.M.	10.4	0.9	9.5
14 Sept 1944	10:10 P.M.	6.2	0.4	5.8
31 Aug 1954	10:15 A.M.	8.8	1.7	7.1
<u>Other Storms</u>				
25 Nov 1950	9:12 P.M.	6.7	0.8	5.9

<u>Hurricanes</u>	<u>Predicted Normal Tide</u>			
	<u>High Tide</u>		<u>Low Tide</u>	
	<u>Time (EST)</u>	<u>Elevation (ft,msl)</u>	<u>Time (EST)</u>	<u>Elevation (ft,msl)</u>
21 Sept 1938	6:46 P.M.	1.9	12:43 P.M.	-1.3
14 and 15 Sept 1944	6:57 P.M.	1.6	1:26 A.M.	-0.9
31 Aug 1954	10:25 A.M.	1.7	4:31 A.M.	-1.0
<u>Other Storms</u>				
25 Nov 1950	9:27 P.M.	0.8	3:45 P.M.	-1.3

* Predicted tide elevation at time
of approximate flood crest

19. FREQUENCY OF TIDAL FLOODING

Although tidal flooding from hurricanes or severe storms has been recorded in Connecticut since the early part of the 17th century, records of elevations are meager until recent years. Chronological lists of hurricanes, through the year 1958 and severe storms, through the year 1956, that caused tidal flooding along the Connecticut coast are given in tables A-1 and A-2 of Appendix A, Hurricane Survey, Interim Report, Mystic, Connecticut, 15 July 1960. Since the year 1956, there have been 4 hurricanes and 10 severe storms that have affected the southern coast of New England. The 4 hurricanes were Brenda (30 July 1960), Donna (12 September 1960), Esther (21 September 1961) and Daisy (6-7 October 1962). The most severe of the 10 storms occurred 19 February 1960. With the exception of hurricane "Donna" which caused moderate tidal flooding, recent hurricanes and severe storms have caused only minor tidal flooding in the Mystic harbor area.

In the preparation of tidal elevation-frequency data for Mystic harbor use was made of similar data prepared for New London harbor, which is located about 6 miles west of Mystic harbor. The U. S. Coast & Geodetic Survey has maintained a recording tide gage at State Pier, New London harbor from July 1938 to the present time. Tidal elevation-frequency data for Mystic harbor, derived from the New London data, are shown in table 1-10. The Mystic harbor frequency curve is shown on plate 1-9 and represents a composite curve based on the 151-year period, 1815-1965, that influences the upper portion of the curve and the 27.5 year period, July 1938 - December 1965, for which there is a continuous tide gage record, that determines the lower portion of the curve.

DESIGN HURRICANE TIDAL FLOOD

20. DESIGN STORM

The design storm used in determining the required height of protective structures for Mystic, Connecticut was developed through the cooperation of the U. S. Weather Bureau and the Coastal Engineering Research Center, assisted by the Texas A. & M. Research Foundation. The design storm, equivalent to the standard project hurricane (SPH), was based on the transposed Cape Hatteras hurricane of September 1944, which is the largest Atlantic coastal storm according to the U. S. Weather Bureau. The SPH criteria were established by enveloping

TABLE 1-10

TIDAL ELEVATIONS VS. FREQUENCY DATA
HURRICANES AND SEVERE STORMS
MYSTIC HARBOR, CONNECTICUT

Hurricane or Storm	Maximum Tidal Elevation (ft,msl)(2)	Frequency Plotting Position Percent Chance of Occurrence in Any 1 Year(1)	
		(1815-1965)	(July 1938- Dec. 1965)
Hurricane, 21 Sept 1938	10.4(3)	0.33	1.8
Hurricane, 31 Aug 1954	8.8(3)	0.99	5.5
Storm, 25 Nov 1950	6.7	-	9.1
Hurricane, 14 Sept 1944	6.2	-	12.7
Hurricane, 12 Sept 1960	6.0	-	16.4
Storm, 7 Nov 1953	5.9	-	20.0
Storm, 19 Feb 1960	5.0	-	23.6
Storm, 12 Nov 1947	4.9	-	27.3
Storm, 3 Mar 1942	4.7	-	30.9
Storm, 30 Nov 1944	4.6	-	34.5
Storm, 16 Feb 1958	4.6	-	38.2
Storm, 30 Nov 1963	4.6	-	41.8
Storm, 16 Mar 1956	4.5	-	45.5
Storm, 20 Mar 1958	4.5	-	49.1
Storm, 9 Mar 1961	4.5	-	52.7
Hurricane, 21 Sept 1961	4.5	-	56.4
Storm, 7 Mar 1962	4.5	-	60.0
Storm, 6 Dec 1962	4.5	-	63.6
Storm, 2 Dec 1942	4.3	-	67.3
Storm, 14 Feb 1960	4.3	-	70.9
Storm, 3 Nov 1951	4.2	-	74.5
Storm, 6 Mar 1943	4.1	-	78.2
Storm, 12 Dec 1944	4.1	-	81.8
Storm, 22 Nov 1945	4.1	-	85.5
Storm, 16 Oct 1955	4.1	-	89.1
Storm, 29 Dec 1959	4.1	-	92.7
Storm, 31 Oct 1947	4.0	-	96.4
Storm, 26 Feb 1960	4.0	-	100.0

(1) Calculated plotting position

$$P = \frac{100 (M-0.5)}{Y}$$

where,

P = percent chance of occurrence in any 1 year

M = number of the event

Y = number of years of record

(2) Based on New London harbor tidal elevation data, stage related to Mystic harbor, except as noted

(3) Based on high watermark elevations at Mystic, Connecticut

observed hurricane parameters of central pressure and radius of maximum winds separately, and smoothing geographically. In deriving the SPH, the 1944 storm was transposed so that it was located entirely over water between Cape Hatteras and the New England coast. The resulting Central Pressure Index (CPI) was about 27.8 inches near the mouth of Narragansett Bay, Buzzards Bay and Long Island Sound. This CPI was approximately 0.5 inch lower than the barometric pressure that actually occurred in September 1944. The center of the transposed hurricane was assumed to move northerly with forward speeds of 30 and 40 knots and along a track passing over New England, 49 nautical miles west of Montauk Point, Long Island, New York.

21. WIND FIELDS

Wind field charts of the transposed September 1944 storm adjusted by SPH indices were prepared originally by the Hydrometeorological Section (HMS), of the U. S. Weather Bureau for Narragansett and Buzzards Bays. The set of charts, showing the hurricane at hourly intervals over the open ocean for forward speeds of 10, 20, 30, 40, 50 and 60 knots and with large radii of maximum winds, are also applicable for Long Island Sound. In general, the faster moving storms produce higher wind velocities. Although 50 or 60-knot storms produce the highest wind velocities, these storms travel so fast that they tend to run ahead of the tidal surge. This results in lower surge build-up than with the 30 or 40-knot storms. Calculations show that the 40-knot storm, with large radii of maximum winds, would cause the greatest surge at Narragansett Bay, Buzzards Bay and the eastern and western portions of Long Island Sound, including Mystic, Connecticut. The 30-knot storm with large radii of maximum winds produced higher surge heights for the central portion of Long Island Sound.

The average half-hour maximum wind velocity from the southeast, over the fetch from Fishers Island to Mystic, is 85 miles per hour for the 40-knot storm as shown in U. S. Weather Bureau Memorandum HUR 7-72, dated 29 December 1960 and entitled: "Transposed September 1944 Hurricane Isovel Charts, SPH Indices, for Pawcatuck, Connecticut, Forward Speed 40 Knots."

A comparison of the wind patterns for a standard project hurricane having 30 and 60-knot forward speeds is given in U. S. Weather Bureau Memorandum HUR 7-66a, dated 21 December 1959, entitled: "A Comparison of Isovel Patterns for September 1944 Hurricane Moving at 30 and 60 Knots." The results showed that the overall wind pattern at 60-knot forward speed as compared to the wind pattern when moving

at 30 knots extended over a slightly larger area with only a small increase in wind velocity.

Wind field data for the design 40-knot storm on the open ocean are shown on isovel charts and tabulations given in HUR 7-55. Isovel charts of the 40-knot storm indicating the maximum wind fields near the mouth of Long Island Sound and at Mystic are shown on plates 1-10 and 1-11, respectively. Corresponding isovel charts of the September 1938 hurricane are shown on plates 1-12 and 1-13.

22. DESIGN STORM SURGE

Analytical computations of the storm surge variations in Long Island Sound for the SPH were carried out for the two critical storm speeds of 30 and 40 knots. The September 1938 storm surge was used as a basis for analytical studies by the Texas A. & M. Research Foundation. The wind fields for the 1938 storm and the transposed 1944 storm furnished by the U. S. Weather Bureau were used to determine the wind stresses over ocean waters and the resulting forced surge over the continental shelf. A description of the method and calculations used are contained in Beach Erosion Board Technical Memorandum 83, "Approximate Response of Water Level on a Sloping Shelf to a Wind Fetch Which Moves Towards Shore," dated June 1956, by R. O. Reid (Texas A. & M.). The design hurricane corresponds to a transposition of the 1944 hurricane which was especially severe off Cape Hatteras with wind field and pressures as specified in U. S. Weather Bureau Memoranda HUR 7-11, 7-13 and 7-21, dated 15 June 1956, 1 August 1956 and 23 January 1957, respectively. This storm was considered to move northward along a path that would cause the region of maximum winds and highest surge to be directed into the eastern entrance of the Sound, off Montauk Point, Long Island. In the Mystic area, to allow for differences between observed and computed surges in the 1938 hurricane, the computed design surge for the 40-knot storm was modified by the ratio of the observed to the computed 1938 surge. This gave a design surge of 12.5 feet for the Mystic area, compared with the experienced surge of 9.5 feet in the 1938 hurricane (see plate 1-14).

23. DESIGN STILLWATER LEVEL

The design stillwater level was determined by adding the design storm surge to the mean spring high water elevation and rounding off to the nearest half-foot as follows:

Surge, Design Storm (feet) (40-knot speed)	12.5
Mean Spring High Water (feet msl)	<u>1.4</u>
	13.9
Round Off Total (feet)	<u>0.1</u>
Design Stillwater Level (feet msl)	14.0

In the Hurricane Survey Interim Report, dated 15 July 1960, the design stillwater level was shown as 14.9 feet msl. This level was determined by adding the same design storm surge of 12.5 feet to the high spring tide, elevation 2.4 feet msl.

The probability of the design storm surge occurring concurrent with the high spring tide is extremely rare. The design stillwater levels of other recently designed projects in New England have been based on the mean rather than the maximum spring high water level.

24. DESIGN WAVE HEIGHTS AND PERIODS

Significant wave heights and periods associated with an average maximum wind velocity of 85 mph from the southeast were derived by methods obtained from the Beach Erosion Board Technical Report No. 4, entitled: "Shore Protection Planning and Design."

Wave refraction diagrams show that the areas east and west of Mason and Sixpenny Islands are vulnerable to waves of periods of 6 seconds or less from the southeast originating near East Point on Fishers Island. Significant wave heights of 5.4 feet and periods of 5.0 seconds at the Noank, Connecticut shore was determined by Bretschneider's Wave and Period Step Method for the 30 nautical mile fetch from East Point on Fishers Island. Applying the wave correction factors for refraction, diffraction and shoaling, reduced the maximum significant wave height from 5.4 to 3.3 feet for the main barrier and land dike "A". Similarly, this significant value of wave height is applicable to the barrier at the Causeway. The maximum significant wave at land dike "B" was further reduced to a 1-foot height by additional refraction, diffraction and shoaling.

The significant wave height, the average of the highest one-third

of the waves in the train, was used to determine the size of riprap, amount of overtopping and top of protection elevation. The maximum wave height is 1.58 times the significant height and has a 1 percent probability in the wave train. This wave was used to determine the height of runup and for the structural design of vertical walls and gates. Waves reaching heights equal to 0.78 of the stillwater depth will break and transform from oscillatory waves to waves of translation.

The average wind velocities from East Point on Fishers Island to the entrance of Mystic harbor during the design hurricane were obtained from the isovel charts in U. S. Weather Bureau Memorandum HUR 7-72, dated 29 December 1960. The maximum average wind of 85 mph was assumed to occur coincident with the design peak stillwater level as did the maximum wind in the 1954 hurricane. The maximum wind in the 1938 hurricane occurred only 15 minutes prior to the 1938 peak stillwater level. Averages of 30-minute time intervals of wind and water surface elevations were used in determining the average height of significant and maximum waves and periods. The significant and maximum wave heights for wind velocities other than maximum were assumed to vary as the square root of the ratio of the wind velocities. The wave periods were determined by the relationship of $H_g/T^2 = 0.22$; where H_g is the significant wave height in feet and T is the period in seconds. The average design wind velocities, wave heights and periods coincident with average stillwater levels for 30-minute time intervals are shown on plate 1-15 and tabulated in table 1-11.

25. TOP ELEVATION OF STRUCTURES

The selected hurricane protection plan for the Mystic area consists of four structures: (a) main barrier, (b) barrier at causeway, (c) land dike "A" and (d) land dike "B". The selected top elevation of 15.5 feet msl was found to result in an acceptable amount of overtopping. A general layout plan of the Mystic structures is shown on plate 1-1.

TABLE 1-11

DESIGN WIND VELOCITIES,
WAVE HEIGHTS AND PERIODS
MYSTIC HARBOR, CONNECTICUT

<u>Time</u> (hour)	<u>Stillwater</u> <u>Level</u> (ft,msl)	<u>Wind</u> <u>Velocity</u> (mph)	<u>H_s</u> <u>Significant</u> <u>Wave Height</u> (feet)	<u>1.58H_s</u> <u>Maximum Wave</u> <u>Height</u> (feet)	<u>Period</u> (sec.)
4:15 - 4:45	8.3	28	1.9	3.0	3.8
4:45 - 5:15	10.7	51	2.5	4.0	4.4
5:15 - 5:45	13.9	74	3.0	4.7	4.8
5:45 - 6:15	14.0	85	3.3	5.2	5.0
6:15 - 6:45	11.4	78	3.1	4.9	4.9
6:45 - 7:15	7.2	62	2.8	4.4	4.6

26. WAVE RUNUP AND OVERTOPPING

Overtopping values were obtained by interpolation and extrapolating of the curves in the Beach Erosion Technical Memorandum No. 64, entitled: "Laboratory Data on Wave Runup and Overtopping on Shore Structures." Since the wave heights in a wave train vary considerably from wave to wave, it was necessary to determine partial values of overtopping associated with each height in the wave spectrum. These values were then weighted according to the relative frequency of occurrence of the particular height and then summed for the final value of overtopping associated with a wave train of given significant height.

Wave runup data were obtained from the Beach Erosion Board Technical Report No. 4 to determine the lower limit of wave heights for which overtopping occurs. Waves that broke seaward of the structure, due to shallow depths, were assumed to reform into lower waves. These waves were redistributed throughout the rest of the height groups according to the proportion of the total number of waves in the group.

The amount of overtopping at the main and causeway barriers and land dike "A" with a top elevation of 15.5 feet msl was estimated about 150 acre-feet extending over a period of $1\frac{1}{2}$ hours. Overtopping at land dike "B" was considered negligible. A summary of the wave runup and overtopping for the various sections along the hurricane structures is shown in table 1-12.

27. VELOCITIES IN NAVIGATION OPENINGS

To determine the velocities through the navigation openings and the effect of the project on normal tide levels in the harbor, an average spring tide was routed through the storage with the gates in the barrier open. A rating curve was developed for the combined flow through the main barrier and the small boat passageway. The open channel flow was assumed in the openings with losses equal to one-half the difference in velocity heads for both contraction and expansion. Therefore, the velocity head in the openings equals the head differential through the openings. Whenever the head differential is in excess of 2.0 feet, water in the small boat opening will flow at critical depth. The loss coefficients were adopted from an analysis of velocity measurements recently made at the New Bedford hurricane barrier.

A graphical summary of the mean spring tide routed through the harbor storage is shown on plate 1-16. Maximum average velocities through the navigation openings for normal tides are shown in table 1-13.

TABLE 1-12
WAVE RUNUP AND OVERTOPPING
MYSTIC, CONNECTICUT

Structure	Elevations		Seaward Face	Length of Structure (ft)	Significant Wave Height (1) (ft)	Maximum Wave Height at Toe (1) (ft)	Maximum Runup (1)		Overtopping			
	Top (ft,msl)	Ground at Toe Average (ft,msl)					Height (ft)	Elevation (ft,msl)	Maximum Rate (1) (cfs)	Volume (1) (ac-ft)	Total Volume (2) (ac-ft)	
<u>Main Barrier</u>												
Sta. 0400 to 1485	15.5	+ 4.0	1 on 2.5(3)	185	3.3	5.2	4.7	18.7	50.0	2.1	3.9	
Sta. 1485 to 6490	15.5	- 1.0	1 on 2.5(3)	505	3.3	5.2	4.7	18.7	136.0	5.6	11.3	
Sta. 6490 to 7430	7.5	+ 7.5	RR Track Opening	40	3.3	5.1(4)	0.0	0.0	0.0	0.0	0.0	
Sta. 7430 to 20455	15.5	0.0	1 on 2.5(3)	1,325	3.3	5.2	4.7	18.7	360.0	14.8	29.5	
Sta. 20455 to 22415	15.5	- 7.0	1 on 2.5(3)	160	3.3	5.2	3.5	17.5	44.0	1.8	3.4	
Sta. 22415 to 22490	15.5	-17.2	Vertical (Steel & Conc.)	75	3.3	5.2	7.6	21.6	22.0	0.9	2.2	
Sta. 22490 to 31415	15.5	- 5.0	1 on 2.5(3)	825	3.3	5.2	3.5	17.5	225.0	9.3	17.5	
Sta. 31415 to 32440	15.5	+ 4.0	1 on 2.5(3)	125	3.3	5.2	4.7	18.7	34.0	1.4	2.8	
Subtotal									871.0	35.9	70.6	
<u>Land Dike "A"</u>												
Sta. 0400 to 1400	15.5	+10.0	1 on 2(3)	100	3.3	3.1(4)	3.8	17.8	23.0	0.9	1.7	
Sta. 1400 to 3450	15.5	+ 5.0	1 on 2(3)	250	3.3	5.2	4.9	18.9	96.0	4.0	7.6	
Sta. 3450 to 4450	15.5	+10.0	1 on 2(3)	100	3.3	3.1(4)	3.8	17.8	23.0	0.9	1.7	
Subtotal									142.0	5.8	11.0	
<u>Barrier at Causeway</u>												
Sta. 0400 to 2425	15.5	+10.0	1 on 2(3)	225	3.3	3.1(4)	3.8	17.8	50.0	2.1	3.8	
Sta. 2425 to 2455	15.5	+ 7.0	Vertical (Steel & Conc.)	30	3.3	5.2	11.8	25.8	14.0	0.6	1.4	
Sta. 2455 to 14488	15.5	+ 3.0	1 on 2(3)	1,233	3.3	5.2	4.9	18.9	469.0	19.3	36.4	
Sta. 14488 to 15400	-6.0	- 6.0	Boat Opening	12	3.3	5.2	0.0	0.0	0.0	0.0	0.0	
Sta. 15400 to 21480	15.5	0.0	1 on 2(3)	680	3.3	5.2	4.9	18.9	261.0	10.8	20.3	
Sta. 21480 to 23420	15.5	+10.0	1 on 2(3)	140	3.3	3.1(4)	3.8	17.8	32.0	1.3	2.4	
Subtotal									826.0	34.1	64.3	
Total									1,839.0	75.8	145.9	

- (1) Based on design stillwater level 14.0 feet msl for 30-minute time interval
(2) Based on duration of overtopping (1½ hours)
(3) Armor stone
(4) Based on breaking wave heights; $H_b = 0.78d$, where d = water depth at toe of structure

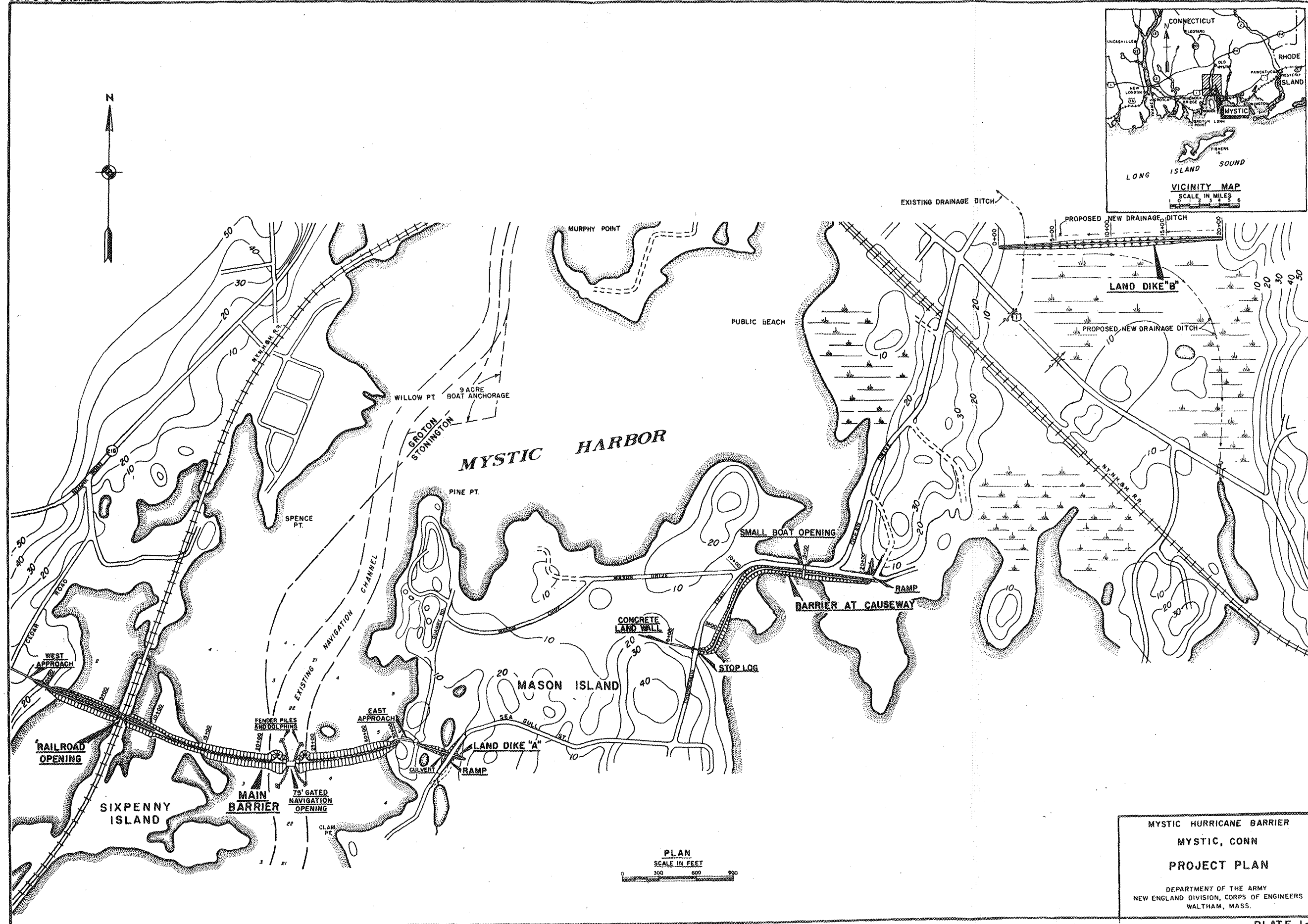
TABLE 1-13

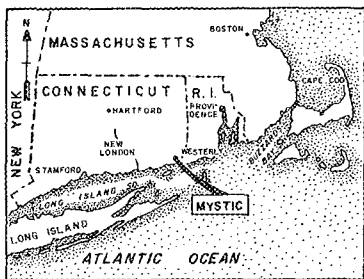
MAXIMUM AVERAGE VELOCITIES
THROUGH NAVIGATION OPENINGS
FOR NORMAL TIDES*
MYSTIC HARBOR, CONNECTICUT

<u>Mean Tide (2.3' Range)</u>	<u>Flood</u>		<u>Ebb</u>	
	<u>Knots</u>	<u>(Ft/Sec)</u>	<u>Knots</u>	<u>(Ft/Sec)</u>
Normal Riverflow	2.4	(4.1)	2.1	(3.5)
Twenty CSM Riverflow	2.0	(3.4)	2.5	(4.2)
<u>Average Spring Tide (2.7' Range)</u>				
Normal Riverflow	2.8	(4.7)	2.5	(4.2)
Twenty CSM Riverflow	2.4	(4.1)	2.9	(4.9)
<u>Maximum Spring Tide (4.2' Range)</u>				
Normal Riverflow	4.3	(7.3)	3.9	(6.6)
Twenty CSM Riverflow	3.9	(6.6)	4.3	(7.3)

* Maximum velocities at center of openings estimated to be 1.3 times the above average figures

7.3
 1.3
 2.19
 3.2
 7.59





LOCATION MAP

SCALE IN MILES
0 20 40 60 80 100



LEDYARD

NORTH STONINGTON

CIDER HILL

GALLUP HILL

QUAKERTOWN

BURNETTS CORNER

OLD MYSTIC

STONINGTON

GROTON

MYSTIC

SIXPENNY ISLAND
BARRIER PLAN

HARBOR

ANDREWS IS.

DODGE IS.

BAKER IS.

Mason Pt.

NOANK

MOUSE IS.

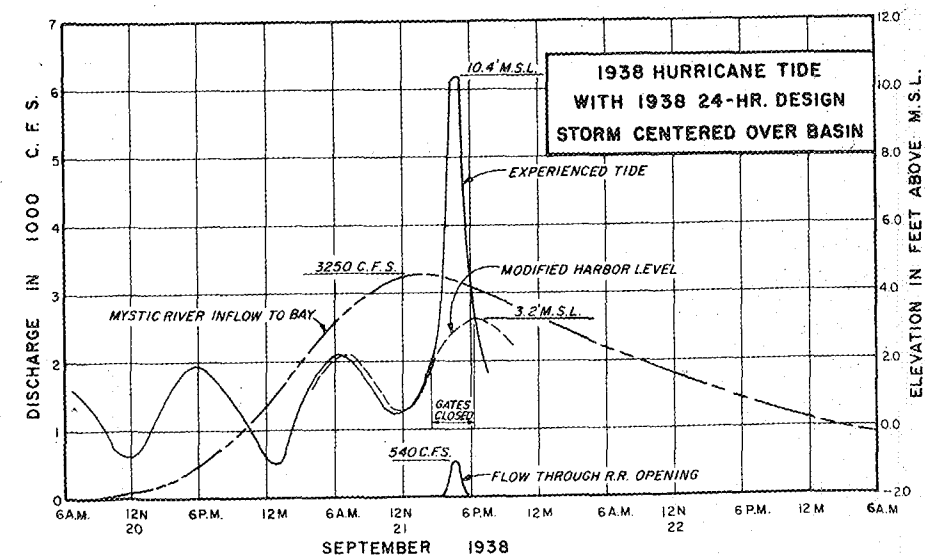
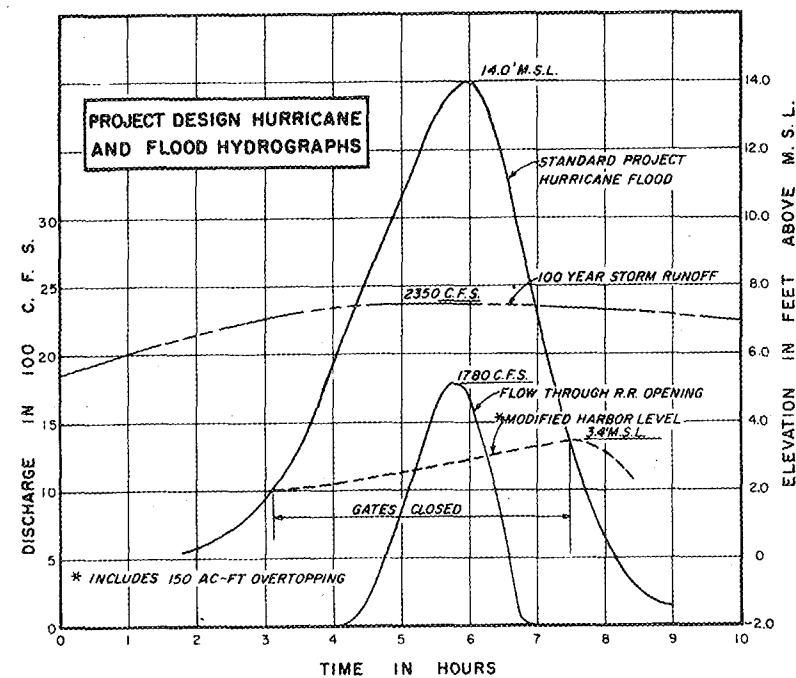
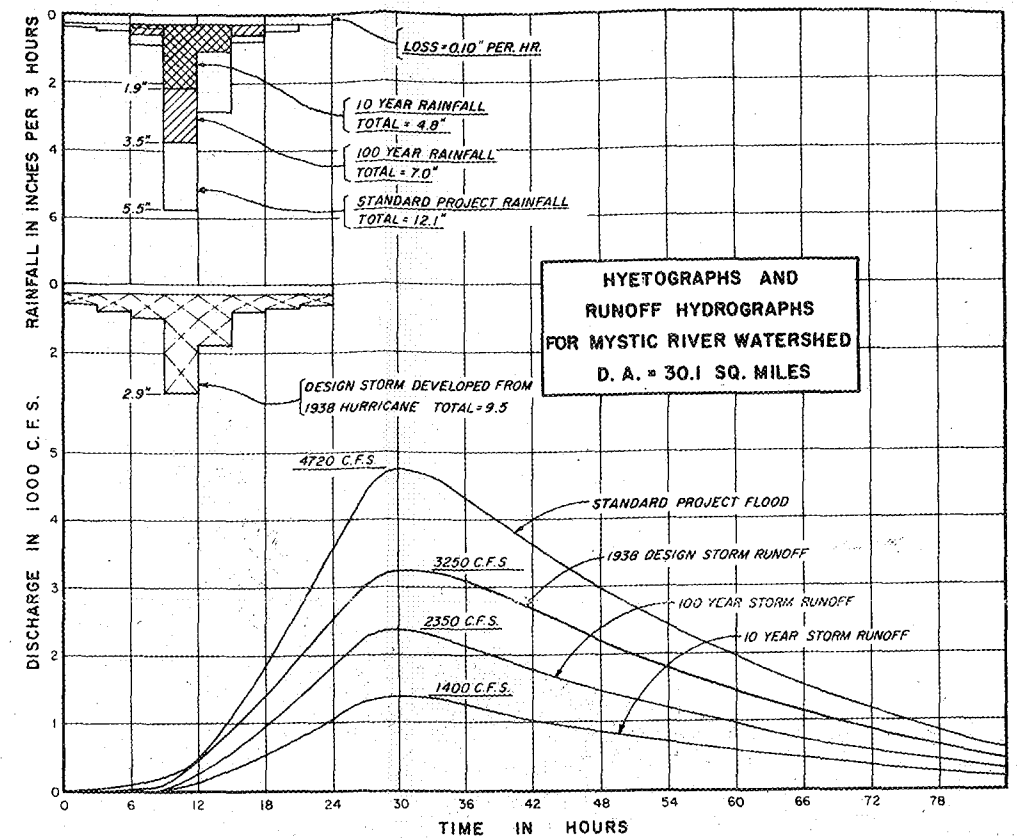
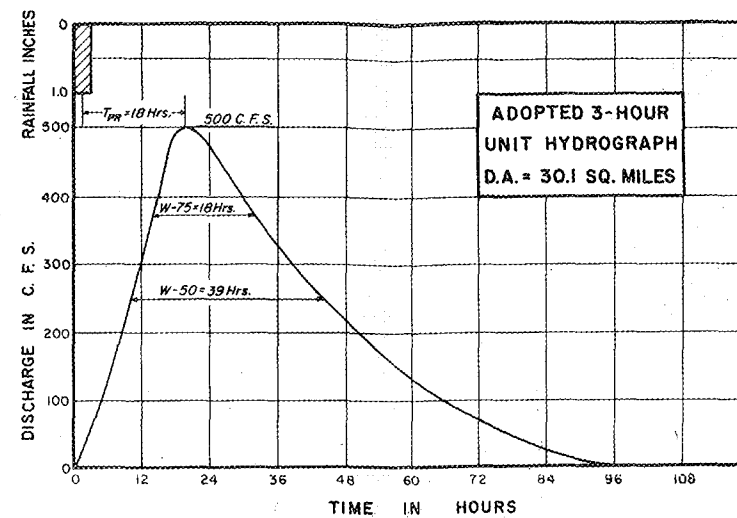
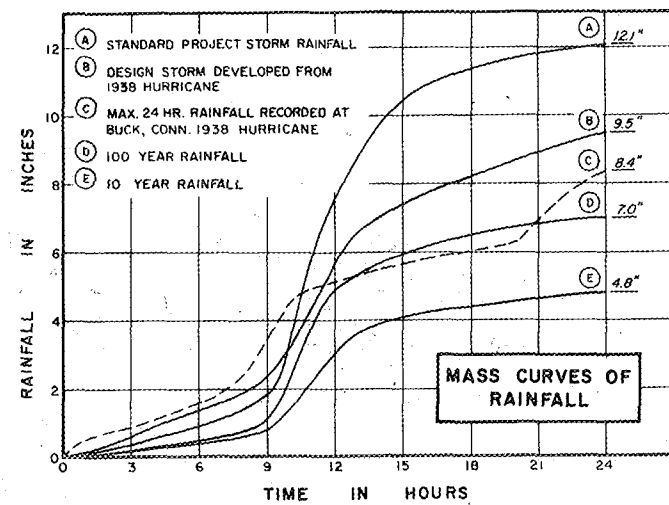
RAM IS.

FISHERS ISLAND SOUND

HURRICANE SURVEY
MYSTIC, CONNECTICUT
DRAINAGE BASIN MAP

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS. MAY 1960

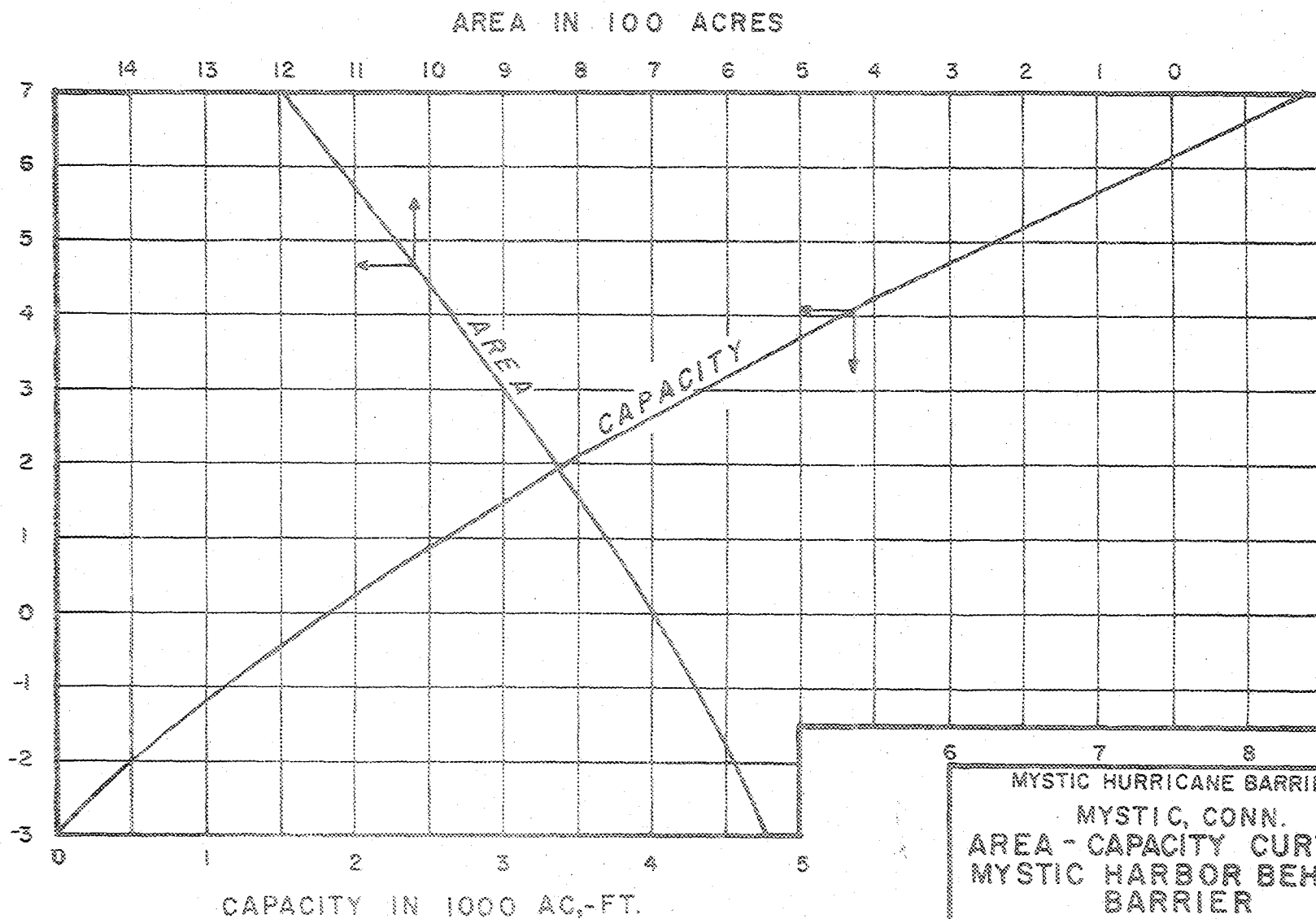
SCALE IN FEET
1000 0 1 2 3 4 5000



MYSTIC HURRICANE BARRIER
MYSTIC, CONN.
HYDROLOGIC DATA
PROJECT DESIGN
AND
SEPTEMBER 1938 HURRICANES

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

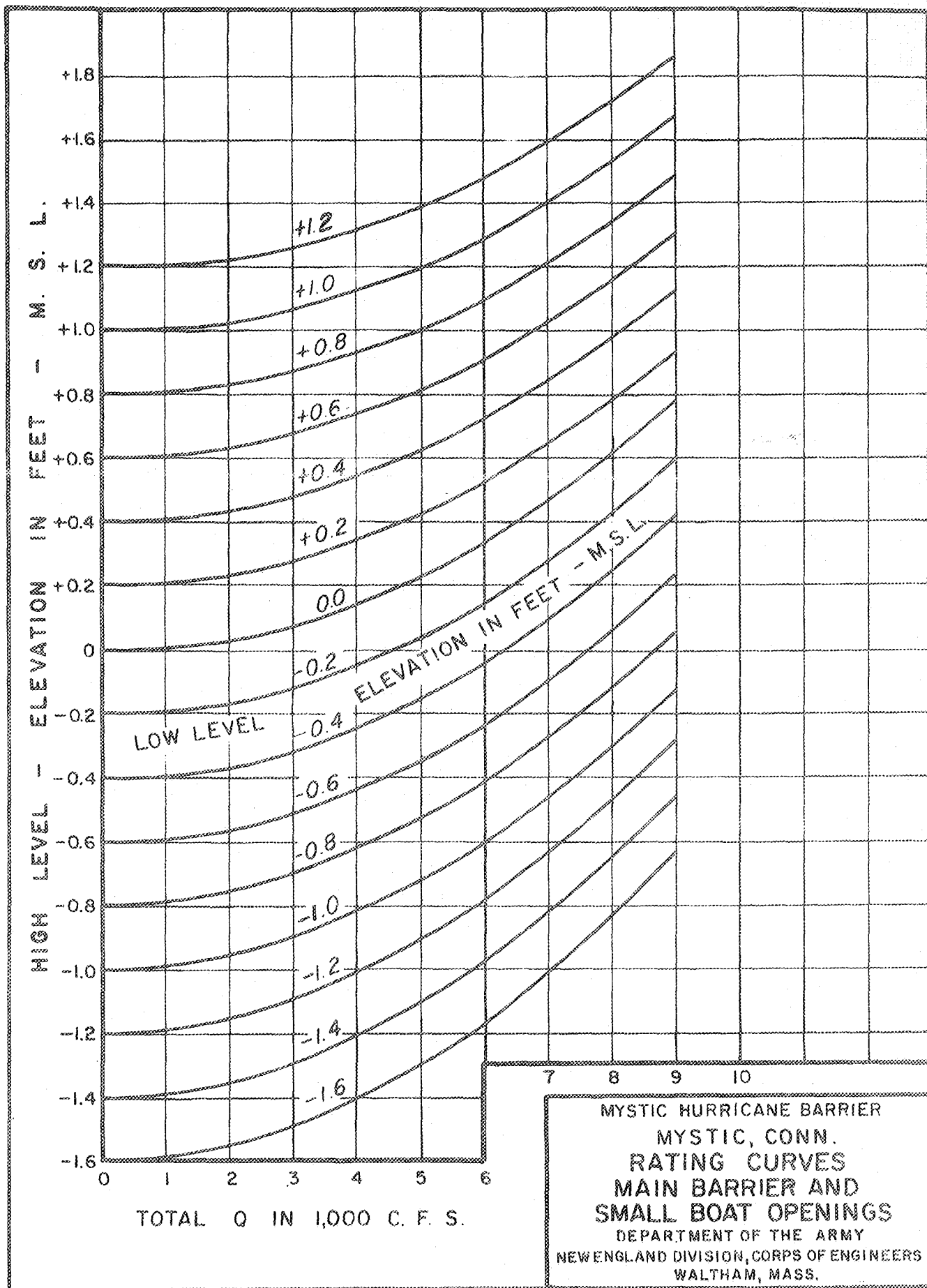
BAY ELEVATION IN FEET - M. S. L.

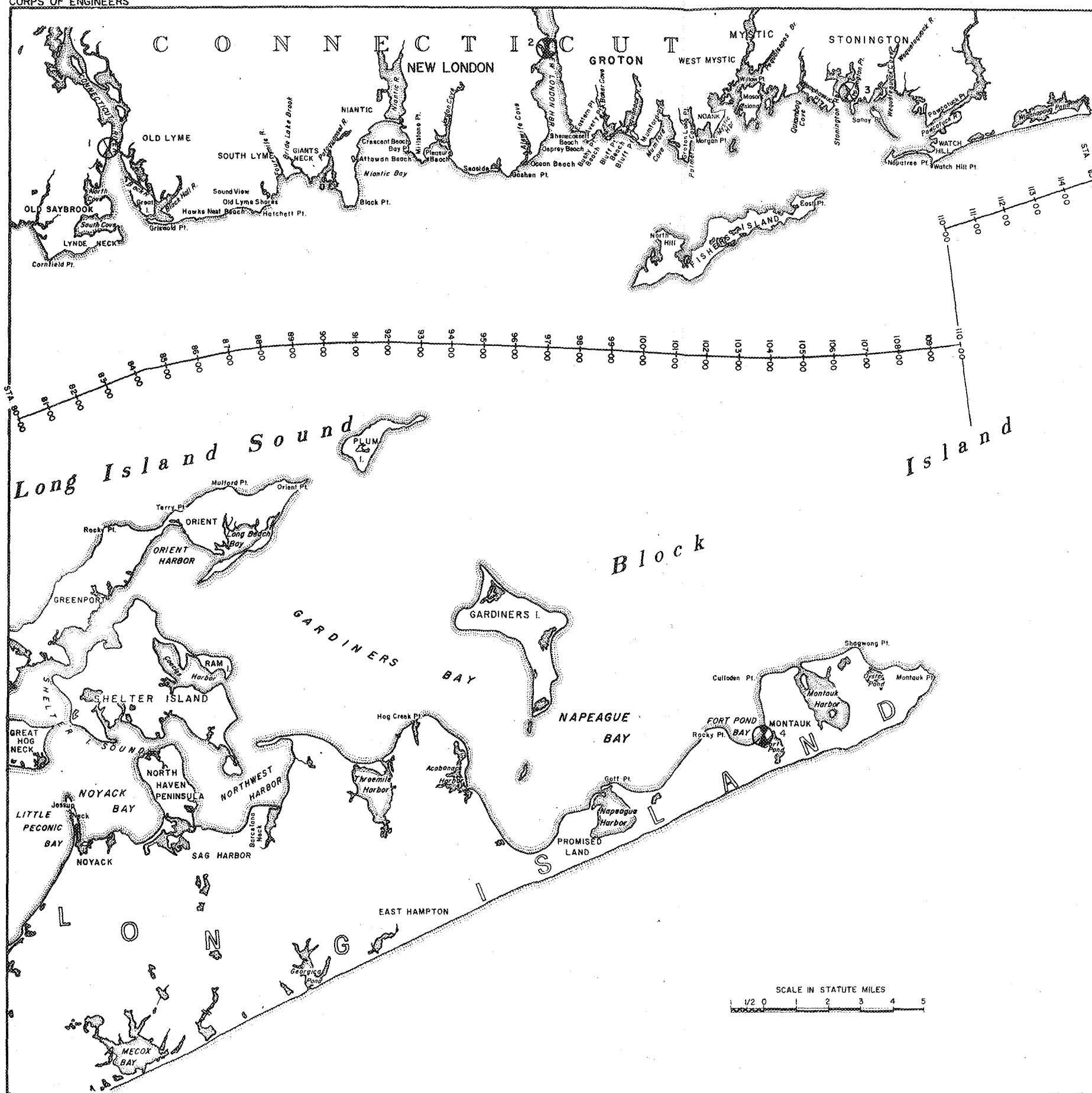


6 7 8

MYSTIC HURRICANE BARRIER
MYSTIC, CONN.
AREA - CAPACITY CURVES
MYSTIC HARBOR BEHIND
BARRIER

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION CORPS OF ENGINEERS
WALTHAM, MASS





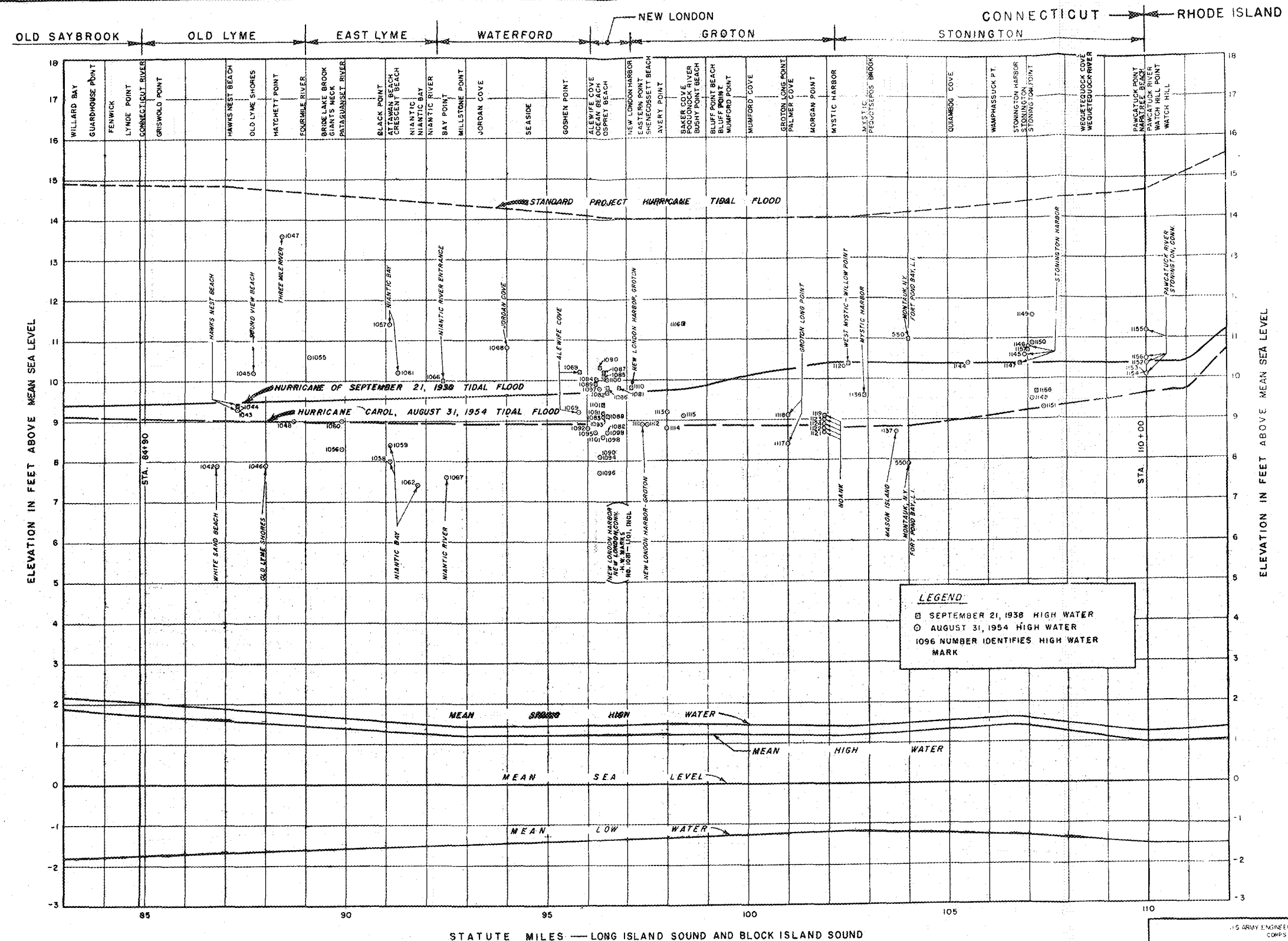
MYSTIC HURRICANE BARRIER
MYSTIC, CONN.

BASE MAP & TIDE GAGE LOCATIONS

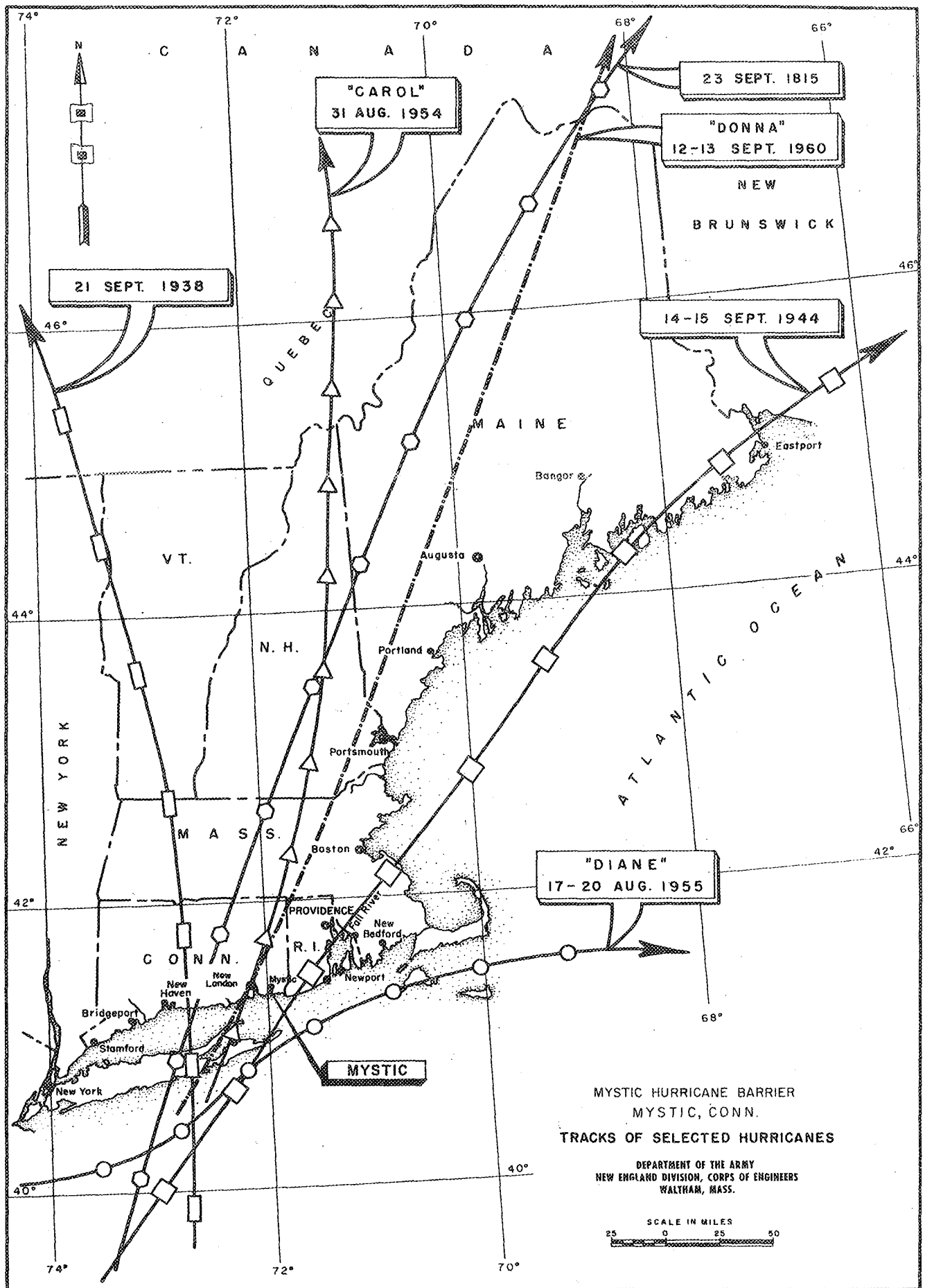
FROM CONNECTICUT RIVER TO
CONNECTICUT-RHODE ISLAND STATE LINE.

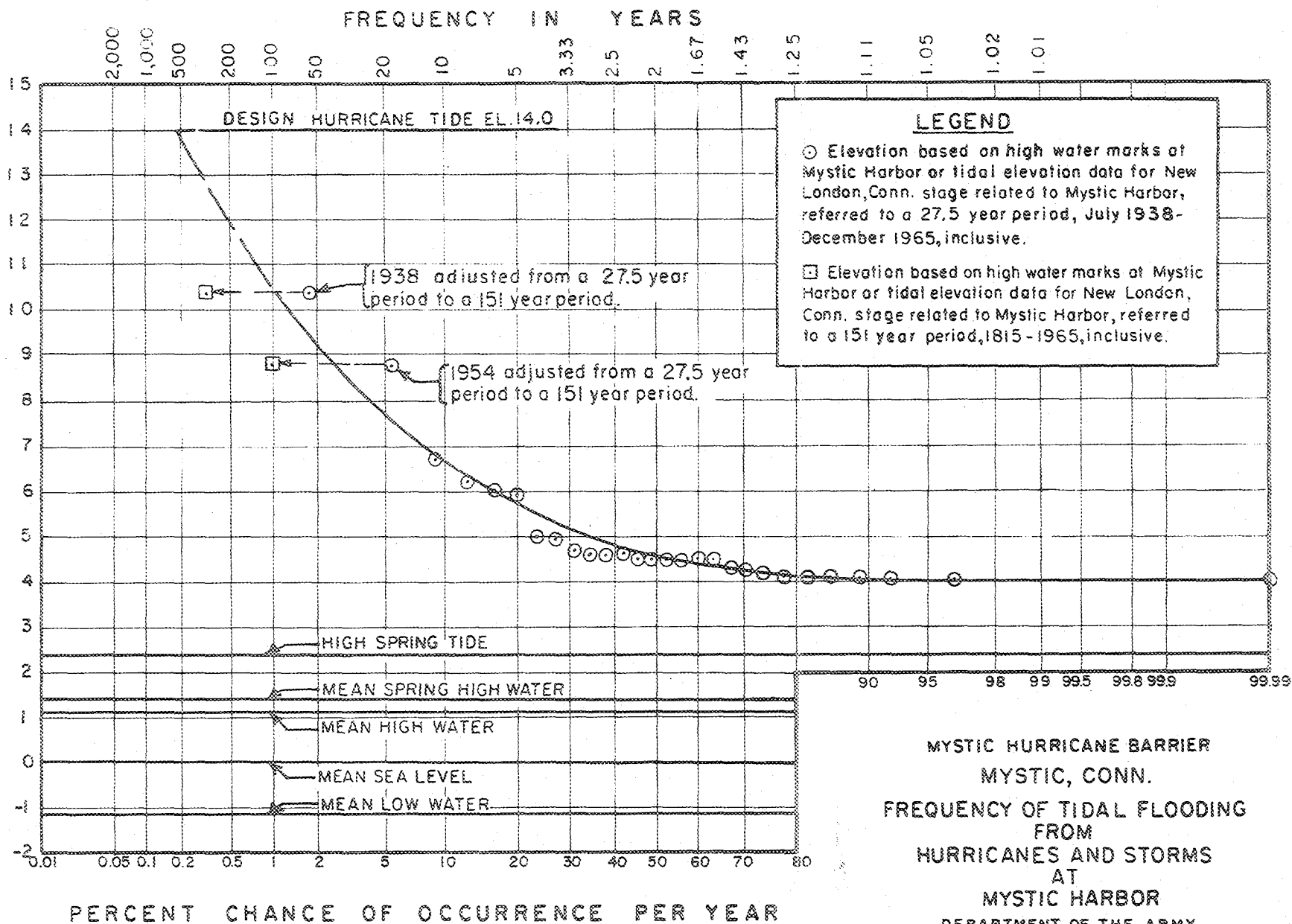
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

SCALE AS SHOWN

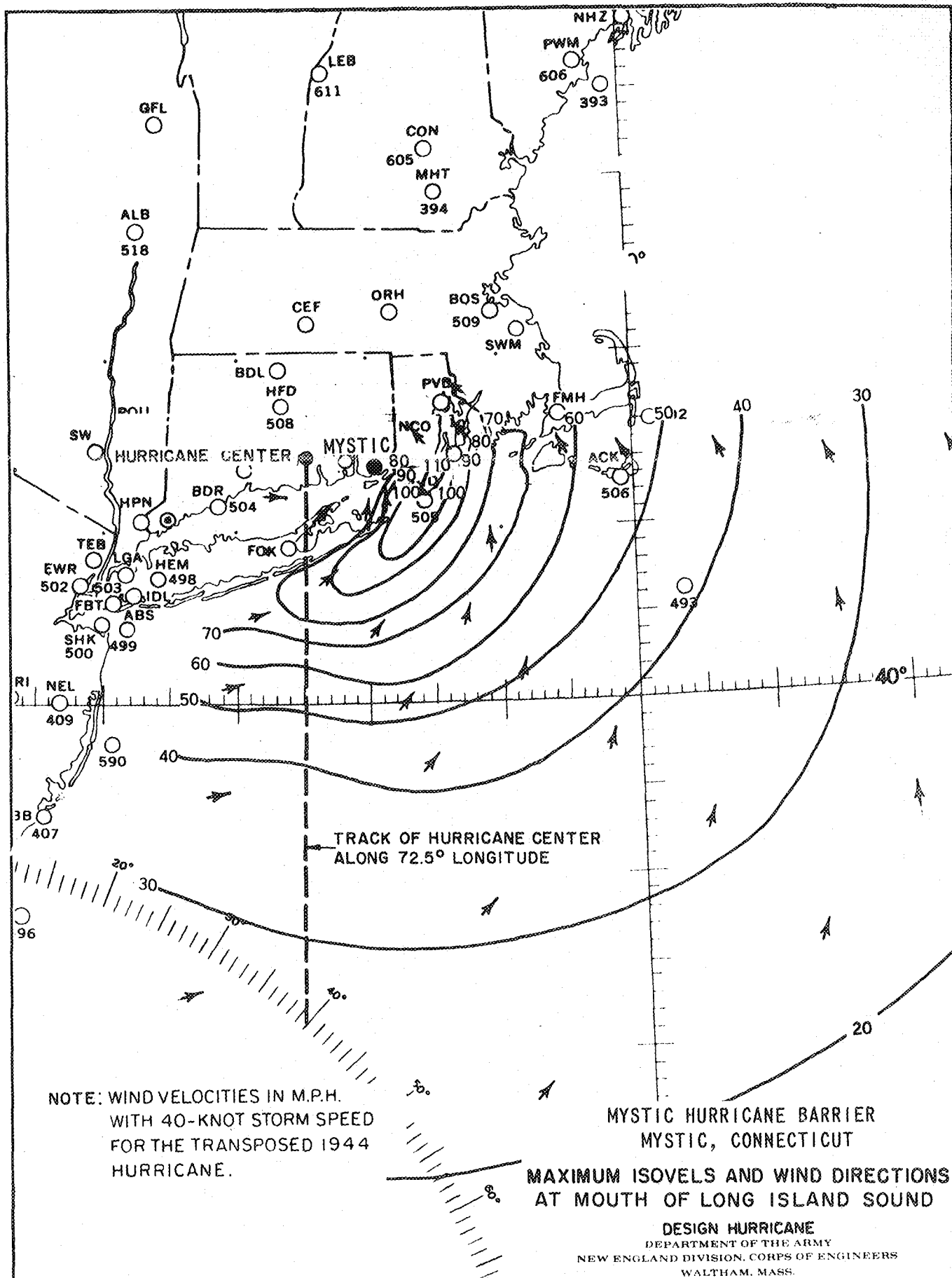


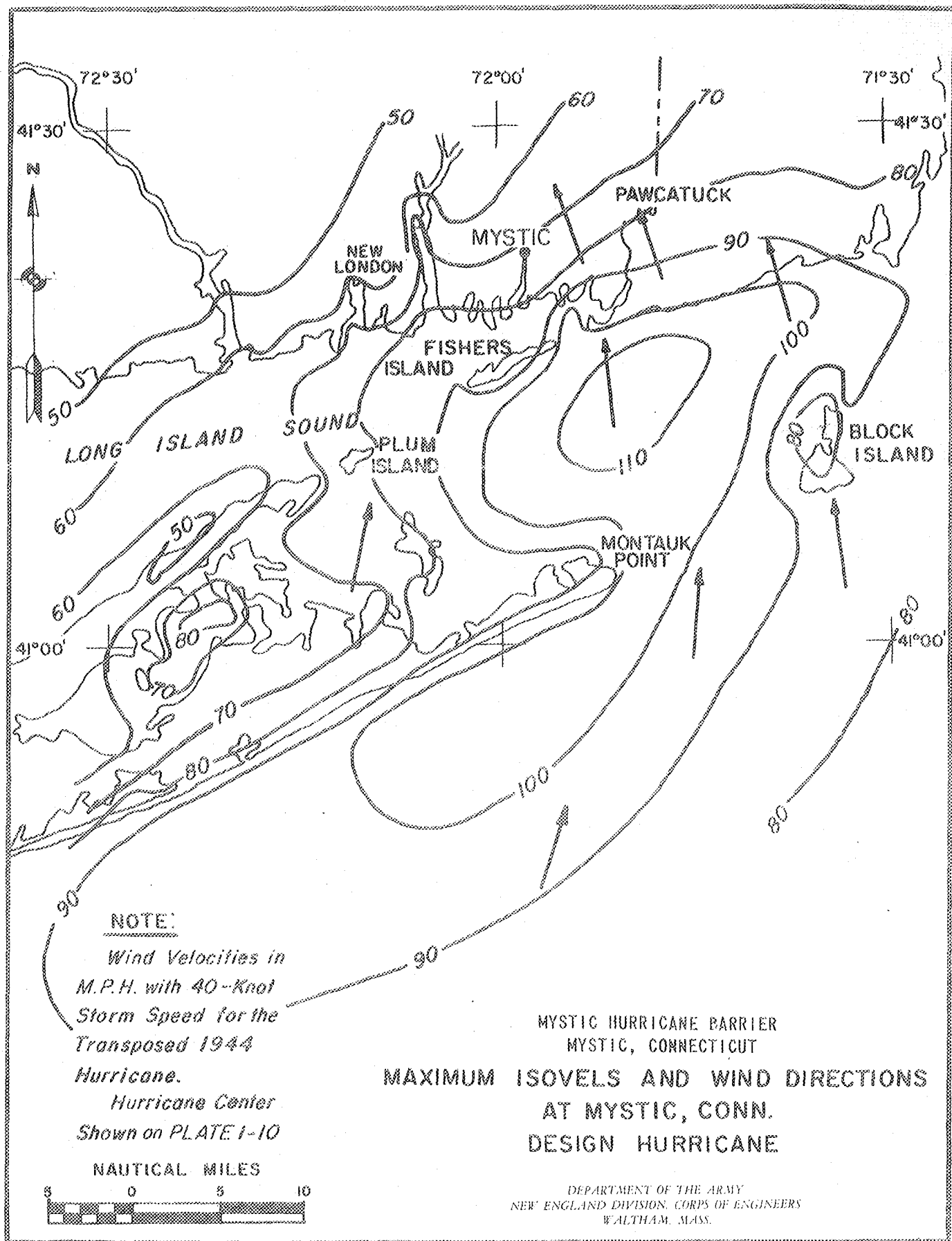
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND CORPS OF ENGINEERS WALTON, MASS.		
MYSTIC HURRICANE BARRIER MYSTIC, CONN.		
HURRICANE FLOOD LEVELS		
FROM CONNECTICUT RIVER TO CONNECTICUT - RHODE ISLAND STATE LINE		
DATE	APPROVED	DATE
ENGINEER	APPROVED	DATE
ENGINEER	APPROVED	DATE
SCALE: AS SHOWN		

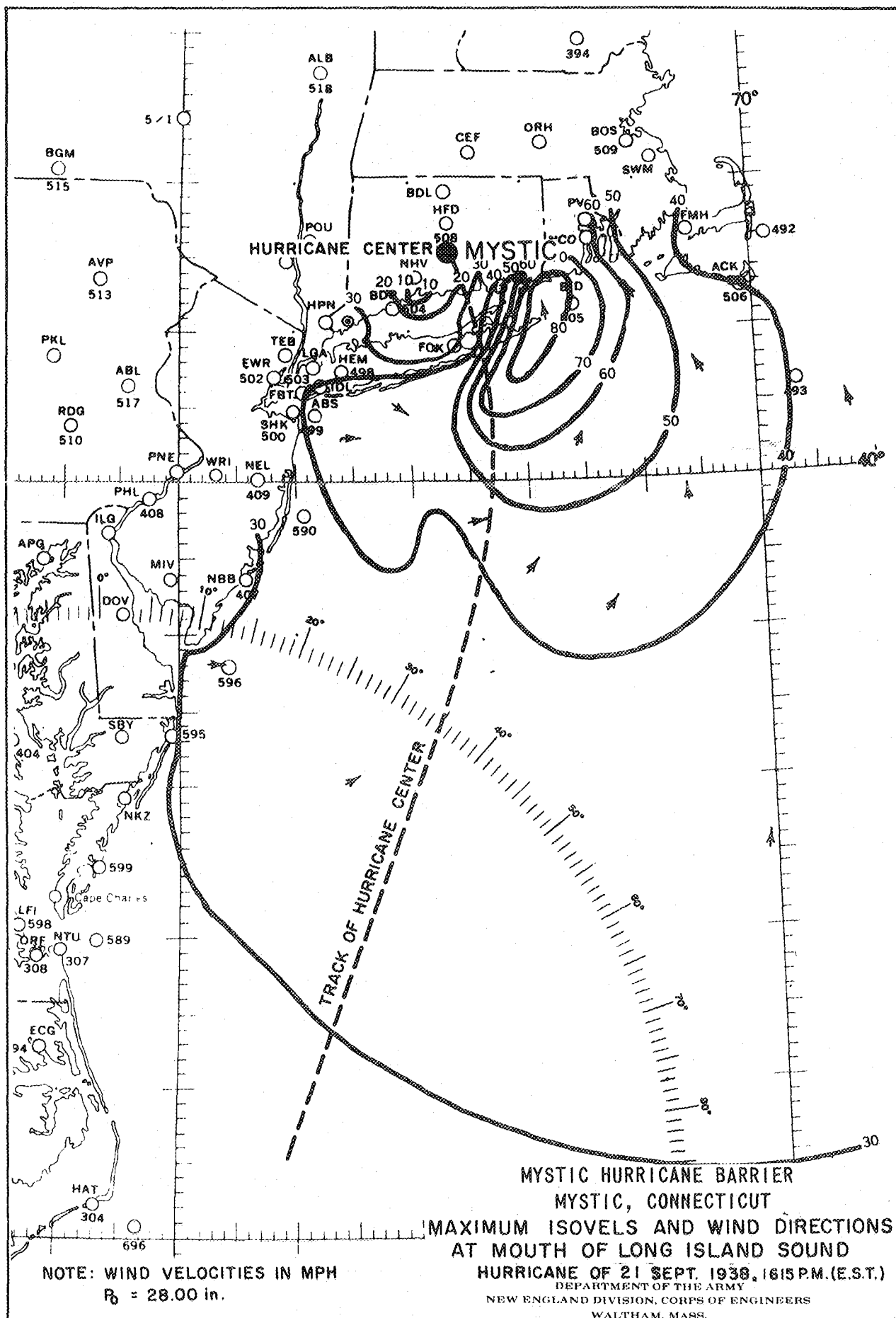


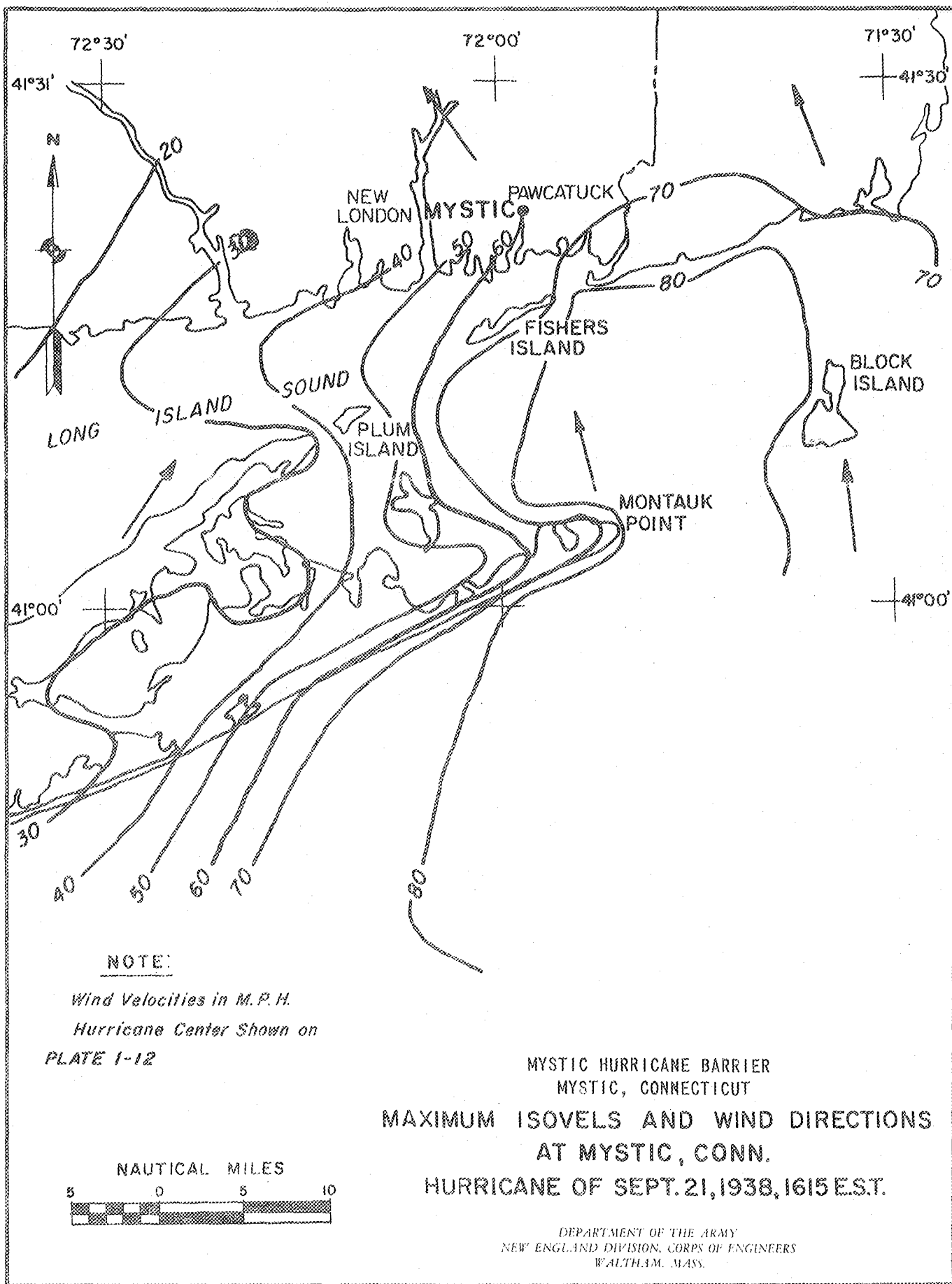


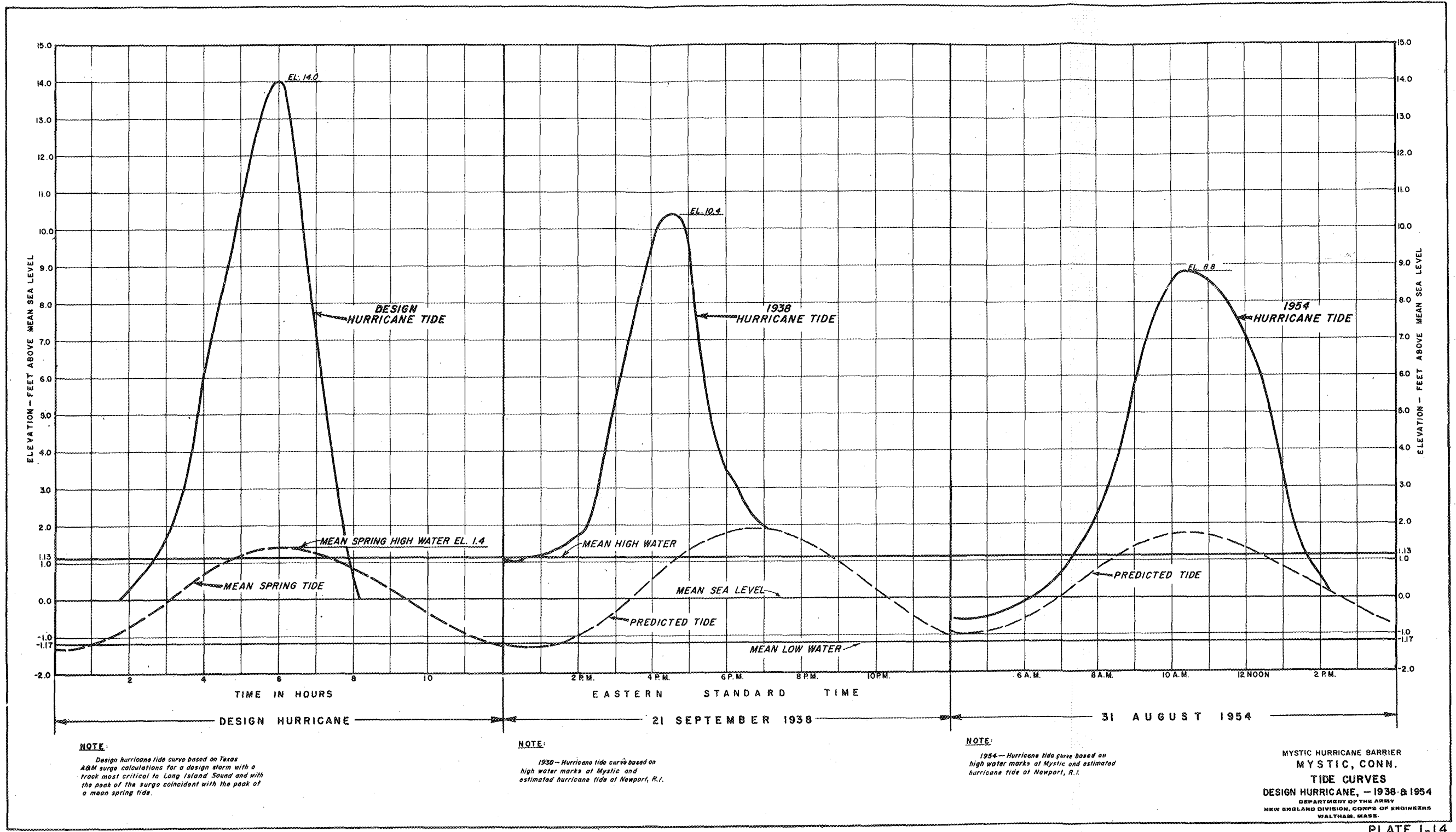
MYSTIC HURRICANE BARRIER
MYSTIC, CONN.
FREQUENCY OF TIDAL FLOODING
FROM
HURRICANES AND STORMS
AT
MYSTIC HARBOR
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

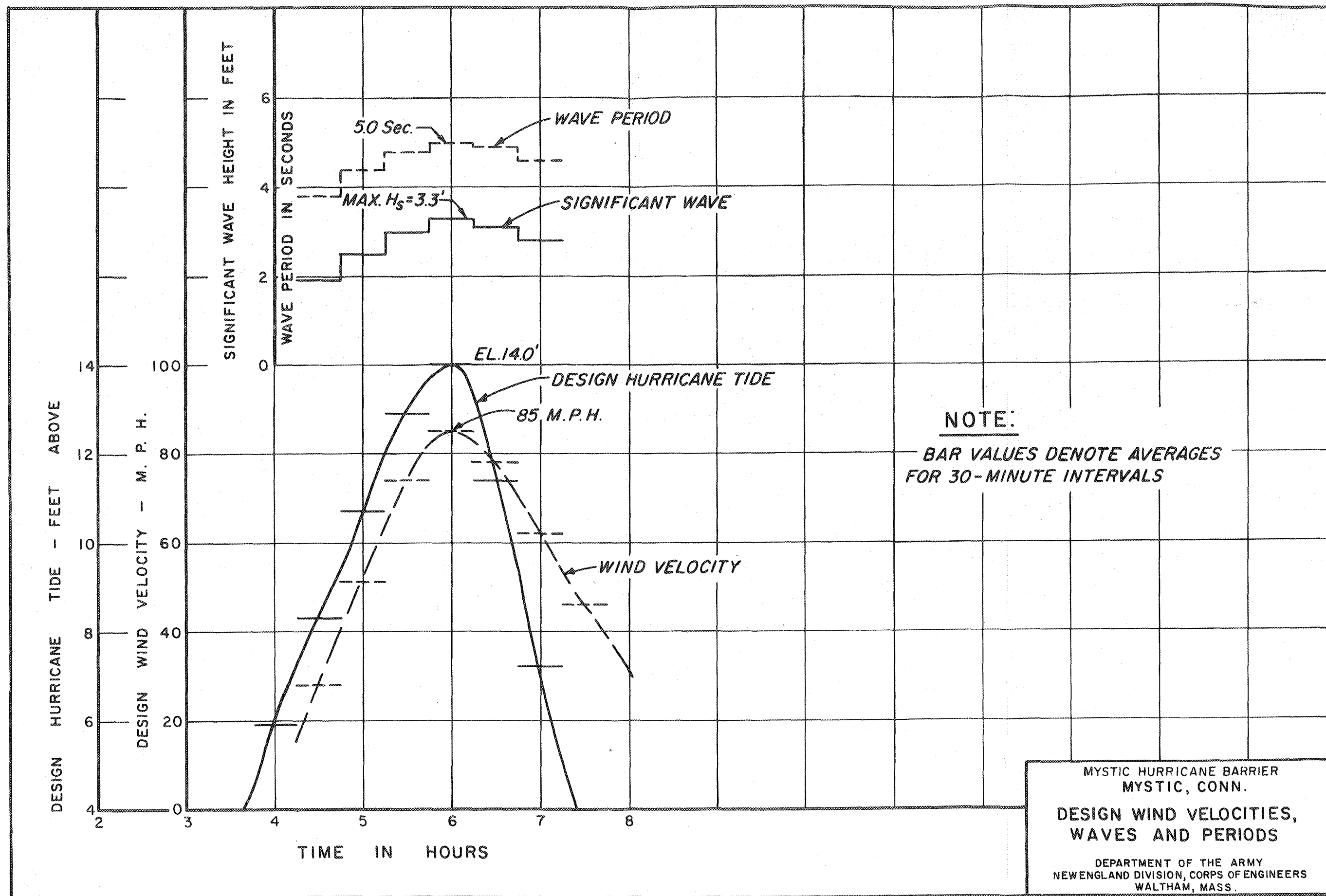












MYSTIC HURRICANE BARRIER
MYSTIC, CONN.
DESIGN WIND VELOCITIES,
WAVES AND PERIODS
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

